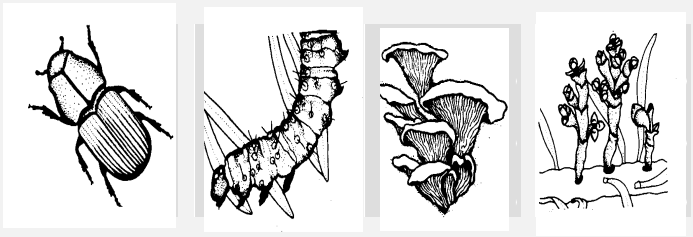
Forest Health Protection



Report 99-11 July 1999

Three-Year Evaluation of Effects of Chlorine on Douglas-fir and Ponderosa Pine near Alberton, Montana

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ABSTRACT

Chlorine gas (Cl_2) was released after a Montana Rail Link train derailed on April 11, 1996 near Alberton, Montana. Short- and long-term effects of chlorine on ponderosa pine and Douglas-fir crowns and mortality were evaluated at two sites between 1996 and 1998. Incidence of insects and pathogens on site trees following the spill were also evaluated. Mortality only occurred to trees less than 3.0 inches d.b.h. at the site nearest the derailment. All but one were ponderosa pine. Too few Douglas-fir were growing on plots near the derailment site to evaluate. No tree mortality occurred at an evaluation site located approximately 4 miles northeast and downwind of the derailment site. Only trees with greater than 70 percent (average 95 percent) total crown damage died following exposure to chlorine. No secondary insects or pathogens were found to be correlated with crown damage.

INTRODUCTION

On April 11, 1996, a Montana Rail Link train derailed near Alberton, Montana, resulting in several train cars releasing chlorine gas (Cl_2). Vegetation surrounding the derailment site was exposed to varying concentrations of chlorine for several days after the spill. Evidence of chlorine damage to plants was present up to 8.5 miles downwind from the spill and appeared to lie below 3,400 feet elevation (Meikle and Ianson 1996).

There have been several studies that have evaluated effects of long-term exposure of vegetation to air pollution from emissions sources such as smelters (Carlson and Dewey 1971, Walsh and Bissell 1979), but little documentation exists on effects of relatively high levels of chlorine over a short duration on growth and mortality of plants. Most documentation of chlorine damage is from long-term exposure to low levels of chlorine, such as near swimming pools, water-purification plants, and sewage-disposal facilities (Sikora and Chappelka 1996).

Injury caused by chlorine is apparently similar to that caused by sulfur dioxide and fluorides (Sikora and Chappelka 1996). Broad-leaved plants may have necrotic, bleached, or tan to brown areas near the leaf margins, tips, and between the principal veins. Conifers may show tipburn on the current season's needles. Studies specifically looking at the effects of chlorine on coniferous trees are very uncommon, but do exist. In a fumigation trial, the threshold chlorine concentration producing visible injury on pine trees was approximately 1.0 ppm (parts per million). Damage included orange-brown necrotic tips of needles, which seemed to become more intense over time (Brennan et al. 1966).

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The objective of this study was to evaluate the immediate and long-term effects of chlorine on coniferous trees near the site of the chlorine spill. Although many plant species were exposed to the chlorine, our interests were in the naturally occurring forest trees. Ponderosa pine (*Pinus ponderosa* Laws) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Bessin) Franco.) were the major forest tree species present in the vicinity of the spill. Approximately 8 weeks after the derailment, we established plots to evaluate effects of chlorine drift and/or ground spill on ponderosa pine and Douglas-fir .

METHODS

We established plots at two sites to monitor and document immediate and future tree mortality, crown damage over time, and association of important insects and pathogens. The first monitoring area was at the derailment site (Spill Site) and the second was approximately 4 miles northeast and downwind of the derailment (Eddy Creek). Eddy Creek was selected based upon accessibility, existing tree damage and Federal ownership.

Spill Site plots were located in a predominantly ponderosa pine stand in close proximity to the derailment site on Montana Rail Link property. Elevation is approximately 3,000 feet. Habitat type at Spill Site is *Ponderosa pine*/*Symphoricarpus albu*s; characterized as having low timber productivity. Mean yield capability is approximately 41 cubic feet/acre/ year (Pfister et al. 1971). Eddy Creek plots were a mixed-age ponderosa pine/Douglas-fir stand on USDA Forest Service land, Lolo National Forest. Plots were located on a south-facing ridge (12-50 percent slope) where elevation is approximately 3,740 feet. Habitat type at Eddy Creek is *Pseudotsuga menziesii*/*Festuca scabrella*; characterized as having low to very low timber productivity. Mean yield capability is approximately 28 cubic feet/acre/year (Pfister et al. 1977).

Variable radius plots (basal area factor 40) with nested 1/10-acre fixed plots were established along a transect at both locations--5 at Spill Site and 14 at Eddy Creek. Plot centers were 2 chains apart. At Spill Site, plots were established along an east-west transect in an area between a county road right-of-way and train tracks. At Eddy Creek, plots were established along a ridge line following north and east transects.

The following tree characteristics were initially recorded: species, diameter at breast height (d.b.h), crown diameter, height, height to live crown, crown class, live crown ratio, and mortality. Ages of trees were taken from the first live, standing sample tree of each species encountered on each plot when moving clockwise from 0 azimuth in eight size classes (see page 415.51 in R-1 stand exam procedures, USDA Forest Service 1991).

At time of plot establishment, condition of tree crowns was also evaluated. Current year, last year and total defoliation were determined as a percentage of foliage that was missing and/or showing symptoms of chlorine damage. Damage included dieback or burning of leaf tips and margins, and chlorosis (Westing 1969, Brennan et al. 1966). Bud break was also recorded and each tree was examined for presence and severity of insect or pathogens and physical defects. In the fall following plot establishment (October 21, 1996), trees were monitored for crown condition, height and mortality. Plots were re-evaluated the following fall (October 21, 1997) with the final monitoring occurring about 2½ years after the derailment (November 12, 1998).

Independent samples t-tests for equality of means were used to test for significant differences (SPSS 1998).

RESULTS AND DISCUSSION

A total of 187 trees were monitored on both sites (tables 1 and 2). Ninety-seven percent of trees on Spill Site plots were ponderosa pine and 3 percent were Douglas-fir. At Eddy Creek, 30 percent were ponderosa pine and 70 percent were Douglas-fir. Every diameter class was represented at Eddy Creek and total number of trees in each class ranged from 8 to 17. At Spill Site, 83 trees were in the 0-2.9 inches diameter class, and several classes were not represented (7-8.9 inches and 12-14.9 inches classes; table 2). Average crown ratio by diameter class for ponderosa pine at Spill Site ranged from 75 to 90 percent (average 76 percent) and crown ratios for the three Douglas-fir ranged from 78-90 percent (average 82 percent;

table 1). At Eddy Creek, average crown ratios of ponderosa pine and Douglas-fir ranged from 10-70 percent (average 46 percent) and 42-85 percent (average 67 percent), respectively (table 2).

Symptoms of chlorine exposure to tree crowns were apparent on many trees at both Eddy Creek and Spill Site plots, although damage was greater in the latter plots (tables 1 and 2). Due to scarcity of Douglas-fir at Spill Site, only crown damage of ponderosa pine was analyzed. Ponderosa pine crown damage ranged from 1-10 percent (average 3 percent) at Eddy Creek, and 40-82 percent (average 75 percent) at Spill Site. Average total crown damage was significantly higher at Spill Site ($p<0.001$; tables 1 and 2), which is also where all mortality occurred.

Sixteen trees at Spill Site had 100 percent crown damage at the time of plot establishment. Of these trees, 75 percent died the first year, 13 percent the second year, and none died the third year. Of the 16 original trees with 100 percent crown damage, only two remained alive 2½ years following the chlorine spill. Proximity of trees to the spill was likely a factor in both crown damage and mortality.

Table 1. Average tree characteristics by diameter class at Spill Site plots (June 1996).

Diameter[1] Class	#Trees (in class)		Avg. Crown Ratio (%)		Average d.b.h. (inches)		Average HT. (feet)		Avg. % Total Dam. (06/96)	
	PP[2]	DF	PP	DF	PP	DF	PP	DF	PP	DF
0-2.9"	82	1	75	90	0.8	0.0	7.1	2.9	77	100
3-4.9"	6	0	84	0	3.5	0.0	15.3	0.0	69	0
5-6.9"	3	0	87	0	5.6	0.0	25.3	0.0	82	0
7-8.9"	0	0	0	0	0.0	0.0	0.0	0.0	0	0
9-11.9"	2	0	85	0	9.3	0.0	42.0	0.0	50	0
12-14.9"	0	0	0	0	0.0	0.0	0.0	0.0	0	0
15-19.9"	1	0	90	0	15.5	0.0	56.0	0.0	40	0
20" or greater	3	2	83	78	26.6	23.4	99.7	74.5	57	93
TOTAL	97	3								
AVERAGE			76	82	2.2	15.6	12.3	50.6	75	95

[1]Diameter at breast height

[2]PP = Ponderosa pine; DF = Douglas-fir

Table 2. Average tree characteristics by diameter class at Eddy Creek plots (June 1996).

Diameter[1] Class	#Trees (in class)		Avg. Crown Ratio (%)		Average d.b.h. (inches)		Average HT. (feet)		Avg. % Total Dam. (06/96)	
	PP[2]	DF	PP	DF	PP	DF	PP	DF	PP	DF
0-2.9"	1	10	10	42	2.9	2.3	13.0	13.3	10	11
3-4.9"	2	6	15	63	3.6	3.8	26.0	21.3	1	16
5-6.9"	3	7	40	73	6.5	6.2	25.8	31.6	1	15
7-8.9"	2	7	40	74	7.9	7.6	21.0	38.0	3	23
9-11.9"	4	13	70	69	11.4	10.6	47.8	48.6	1	12
12-14.9"	3	5	57	85	14.3	13.1	56.7	48.2	1	16
15-19.9"	4	6	58	75	17.7	17.5	67.0	53.3	8	15
20" or greater	6	3	40	77	28.0	34.7	85.7	83.0	1	4
TOTAL	25	57								
AVERAGE			46	67	14.9	9.7	53.1	38.4	3	14

[1]Diameter at breast height

[2]PP = Ponderosa pine; DF = Douglas-fir

A total of 21 ponderosa pine and 1 Douglas-fir died over the 2½ years of monitoring (table 3). All mortality occurred at Spill Site plots in the 0-2.9 inches diameter class. Most mortality occurred during the first growing season after the derailment. Trees that died displayed very high levels of crown damage following the spill (average 95 percent). This is similar to insect defoliation in Douglas-fir, such as caused by Douglas-fir tussock moth (*Orgyia pseudotsugata* McDonald). Mortality related to defoliation is more common in smaller trees and generally occurs only after more than 90 percent of foliage has been lost (Wickman 1978).

The differences in average tree characteristics between live and dead ponderosa pine in the 0-2.9 inches diameter class at Spill Site plots were found to be statistically significant ($p<0.001$; table 4). Live ponderosa pine less than 3.0 inches diameter at breast height (d.b.h.) at Spill Site were significantly bigger, had more live crown, and suffered less damage than killed ponderosa pine in the same size class. This may indicate that crown damage is more likely to occur, and be more severe, in smaller trees.

Primary effect of acute chlorine exposure to vegetation is needle burning (Brennan et al. 1966) and subsequent needle loss (Sikora and Chappelka 1996). Varying amounts of needle burning and needle loss were apparent at both Eddy Creek and Spill Site plots. Because chlorides do not accumulate in plant tissue after exposure (Sikora and Chappelka 1996), crown damage should decrease over time as new growth occurs. Crown damage for ponderosa pine at Spill Site tended to decrease over time, although damage to larger trees increased during the first growing season following the derailment then decreased during the second growing season (figure 1). This apparent increase in crown damage for the two largest size classes at the October 1996 measurement could be due to inaccuracy of measuring crown damage on larger trees. The last measurement (October 1997) did show an overall decrease in total damage from the initial measurement. Crown damage did not follow

a trend over time at the Eddy Creek plots. Factors influencing extent of damage to plants from air pollutants include distance from source, length of exposure, meteorological conditions (Sikora and Chappelka 1996), and possibly time of year of exposure. Timing of this spill, early spring before bud break, probably lessened potential effects. Trees in a hardened condition have been shown to be less sensitive than actively growing trees (Brennan et al. 1966).

Site conditions probably played a minimal role in the differences in crown damage and mortality at the two sites. Tree density (as measured by stand density index) was actually less at Spill Site than at Eddy Creek. Habitat types at both sites indicate low timber productivity, with productivity potential being slightly higher at Spill Site (table 5).

Table 3. Average characteristics of mortality occurring between 1996-1998 at the Spill Site plots.

Mortality Reading	#Trees		Avg. Crown Ratio (%)		Average d.b.h. (inches)		Average HT. (feet)		Avg. % Total Dam. (06/96)	
	PP[1]	DF	PP	DF	PP	DF	PP	DF	PP	DF
06/96	0	0	0	0	0	0	0	0	0	0
10/96	15	1	63	90	0.2	0.0	3.9	2.9	96	100
10/97	4	0	42	0	0.2	0.0	4.9	0.0	92	0
11/98	2	0	92	0	0.6	0.0	5.1	0.0	92	0
TOTAL	21	1								
AVERAGE			61	90	0.2	0.0	4.2	2.9	95	100

[1]PP = ponderosa pine; DF = Douglas-fir

Table 4. Average tree characteristics of live vs. dead ponderosa pine trees at the Spill Site plots at the October 1996 remeasurement.[1]

Tree Class	#Trees	Avg. Crown Ratio (%)[2]	Average d.b.h. (inches)[2]	Average HT. (feet)[2]	Avg. % Total Dam. (06/96)[2]
0-2.9" Live	67	78[a]	0.9[a]	7.8[a]	73[a]
0-2.9" Dead	15	63[b]	0.2[b]	3.9[b]	96[b]

[1]All mortality was confined to the 0-2.9 inches d.b.h. size class and occurred only at Spill Site.

[2]Values with different superscript letters within columns are significantly different at $p<0.001$.

Figure 1. Average crown damage over time for ponderosa pine at Ground Zero plots.

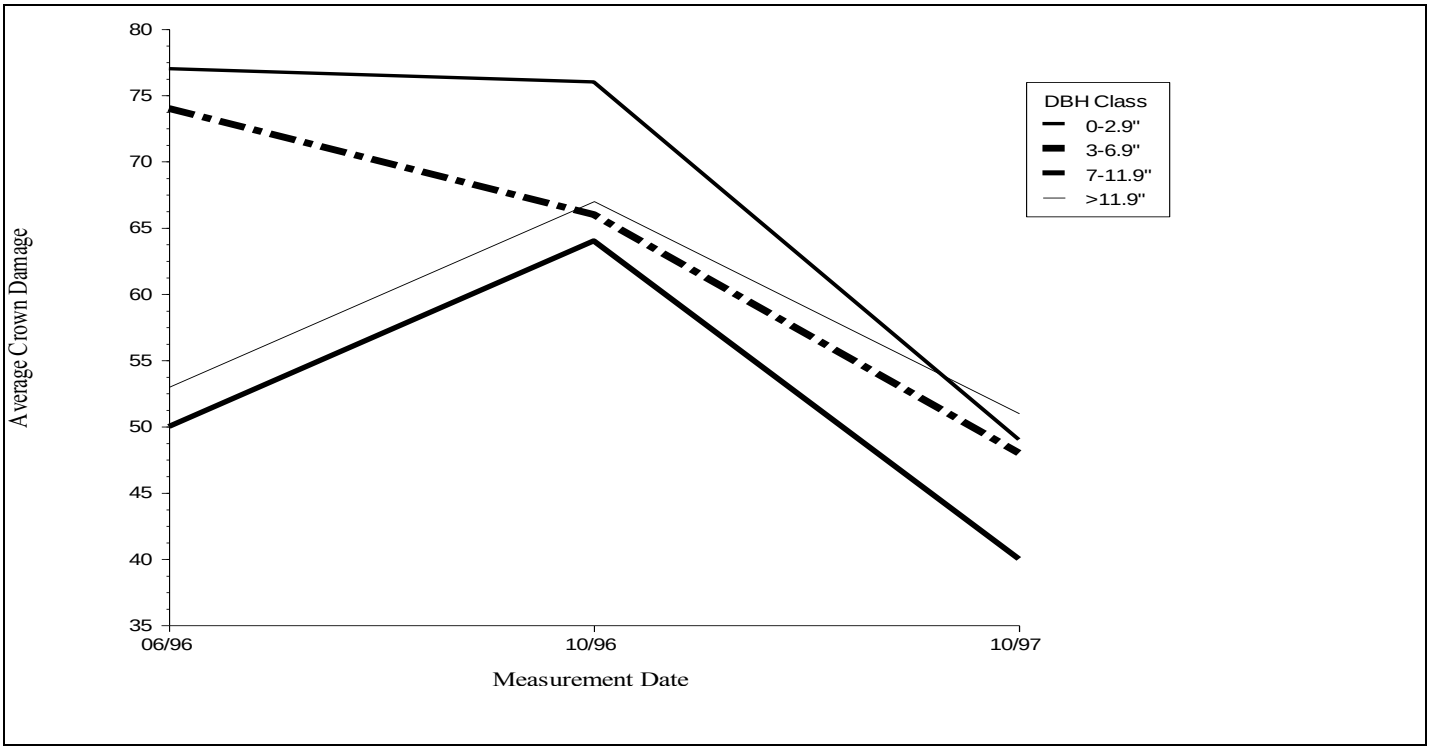

Table 5. Average stand characteristics for Spill Site and Eddy Creek plots.

Site	SDI[1]	BA[2]	QMD[3]	CCF[4]	TPA[5]	Hab Typ[6]
Spill Site	188	90	7.2	72	319	*Pipo/Syal*
Eddy Creek	336	181	9.6	186	358	*Psme/Fesc*

[1]SDI = Stand density index

[2]$_{BA}$ = Basal area (square feet per acre)

[3]QMD = Quadratic mean diameter (diameter of the cross-section of average area)

[4]CCF = Crown competition factor

[5]TPA = Trees per acre

[6]HabTyp = Habitat type, Pipo/Syal = *Pinus ponderosa*/*Symphoricarpus albus*,
Psme/Fesc = *Pseudotsuga menziesii*/*Festuca scabrella*

The most common damage on Eddy Creek plots was top-kill. Most was attributed to comandra blister rust damage (*Cronartium comandrae* Peck) on ponderosa pine, and branch dieback from previous western spruce budworm damage (*Choristoneura occidentalis* Freeman) on Douglas-fir. Bole sweeps and forking were also frequently noted in both species. The most common damages noted on Spill Site plots were mechanical damage to base of larger trees, and actual "mowing down" of smaller trees. Data collected on insect and pathogen incidence, as well as physical defects, showed no correlation with crown damage, although secondary agents may influence future mortality. At the 1998 remeasurement, we noted Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) attacks on a Douglas-fir that also had root-disease-caused basal resinosis. Incidence of these agents cannot be reliably tied to damage from the chlorine spill. There is currently an elevated level of Douglas-fir beetle activity in the surrounding area (R1 Aerial Survey, 1996-1998), and Douglas-fir beetle attacks are often associated with root-diseased trees (Goheen and Hansen 1993).

Very little data exists on effects of chlorine on vegetation. Chlorine spill from the Montana Rail Link derailment has allowed us to evaluate effects of a one-time chlorine exposure on conifers. Although data is not conclusive, they do suggest chlorine did cause enough crown damage in small ponderosa pine near the derailment site to cause mortality. Short- and long-term effects of chlorine on conifer growth may be affected, but were not evaluated in this study.

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